
Report from Sessions 1 and 3, including the Local Bubble Debate

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Abstract This report summarizes the discussions in the Session 1 and Session 3 groups which met to discuss the questions: “What Physical Processes Drive the Multiphase Interstellar Medium in the Local Bubble?”, and “What are the Energy and Pressure Balances in the Local Bubble?” Most of our understanding of the Local Bubble has come from soft X-ray observations, but recent appreciation of the importance of solar wind charge exchange (SWCX) reactions has shown that the heliosphere produces some fraction of the soft X-rays that were previously ascribed to the Local Bubble. Some astronomers suggest that the SWCX X-rays rather than Local Bubble emission could explain most of the locally produced X-rays. Our discussions, therefore, also included a debate concerning the Local Bubble’s existence.

Keywords Galaxy: Local Bubble — Solar System: Solar Wind – Galaxy: ISM — Observations: Diffuse X-rays — ultraviolet: O VI

1 Introduction

The workshop conveners created small groups which were asked to discuss issues related to the heliosphere and the Local Bubble (LB). The members of Sessions 1 and 3 combined to discuss the physical processes within and pressure and energy balances of the LB. While these topics assume that the LB actually exists, this assumption is debatable because the traditional evidence for a hot LB (soft X-rays that originate within a few hundred parsecs of the Earth and are seen in all directions) could possibly be due to another, recently discovered source. That source, solar wind charge exchange (SWCX) is outlined in Section 2. The debate over the Local Bubble’s existence is presented in Section 3. In Section 4, we summarize the discussion of the pressure and energy balances within the Local Bubble. The discussion of the pressure balance allows for the possibility that the LB gas pressure is smaller than previously assumed due to the SWCX component, but the later discussions assume the traditional conception of the LB as containing hot gas. In Section 5, we summarize the discussion of clouds within the Local Bubble, and in Section 6, we discuss other important physical processes. This report follows the arguments presented at the session and later presented to the workshop participants for their comments.

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2 Solar Wind Charge Exchange (SWCX)

1. The solar wind is highly charged. When solar wind ions encounter neutral gas (in the coma of comets, in planetary atmospheres, and dispersed within the heliosphere), they have a high probability of capturing an electron from the neutral atom.
2. An example using solar wind element “X”: $X^{(n+1)+} + H \text{ or } He \Rightarrow X^{n+*} + H^+ \text{ or } He^+$.
3. Since the electron is transferred into a highly excited orbital (denoted by *), the charge transfer is soon followed by de-excitation and radiation of at least one X-ray photon. The resulting X-rays are colloquially referred to as SWCX X-rays.
4. Cravens (2000) and Robertson & Cravens (2003) proposed that $\sim 50\%$ of the observed 1/4 keV flux previously attributed to the LB is due to SWCX in the heliosphere.
5. In the 3/4 keV band, Koutroumpa et al. (2007) proposed that SWCX can explain $\sim 100\%$ of the observed O VII X-ray flux previously attributed to the LB.
6. Charge exchange and the subsequent release of X-ray photons are being studied currently with more refined reaction rates expected in the near future.
7. The SWCX intensity depends on the Sun’s activity level, which varies with time.

3 After We Consider the Effects of SWCX, Is There Reason to Believe that the LB Actually Exists? — the Local Bubble vs Solar Wind Charge Exchange Debate

Below, we present the arguments for (left column) and against (right column) the existence of the Local Bubble:

Pro Local Bubble

1.) *X-Ray Argument: SWCX explains only a fraction of the observed “locally produced” X-rays, the remainder must come from the Local Bubble:*

- A Cravens (2000) and Robertson & Cravens (2003) predicted that $\sim 1/2$ of the diffuse 1/4 keV X-rays observed in the Galactic plane by *ROSAT* are from SWCX. The remainder must be from the LB.
 - The Robertson & Cravens predictions were made for the same lines of sight through the heliosphere as were used in the *ROSAT* survey
- B The distribution of SWCX 1/4 keV photons (see map in Robertson & Cravens (2003)) differs significantly from the observed distribution (see map in Snowden et al. (1998)). The difference must be due to the hot LB contribution.

Anti Local Bubble

1.) *X-Ray Argument: SWCX generates all of the “locally produced” 3/4 keV X-rays, so there is no need to assume the existence of a Local Bubble:*

- A SWCX predictions for 2 sample LB observations explain all of the observed local O VII and O VIII emission at 0.57 and 0.65 keV (Koutroumpa et al. 2007).
 - These calculations were done for the same lines of sight through the heliosphere as the *Chandra*, *XMM*, and *Suzaku* observations.
 - These calculations included the SWCX enhancements associated with coronal mass ejections.

3.) *EUV Counter-Argument: The CHIPS and EUVE measurements are ambiguous*

A Responses:

- The models assumed CIE and solar abundances of gas-phase iron. Either assumption could be incorrect
- The *EUVE* observations are thought to have been contaminated by a very soft X-ray leak.
- The calorimeter (McCammon et al. 2002) saw a much larger intensity in the 170 Å region than did *CHIPS* or *EUVE*.

3.) *EUV Argument: LB models predict Extreme UV emission that was not seen by EUVE or CHIPS*

- A *EUVE* and *CHIPS* did not find as much Fe VIII to Fe XI emission around 170 Å as expected from models of the hot LB (Jelinsky et al. 1995; Vallergera & Slavin, 1998; Hurwitz et al. 2005).

4.) *Local Cavity and Local Cloud Argument (also see Section 4):*

- A The Local Cavity with little H I (Lallement et al. 2003) must be filled with ionized gas (such as the LB), otherwise it would collapse. Similarly, the Local Interstellar Cloud (see other articles in this volume) would expand if it were not compressed by the Local Bubble's pressure.

- Response: Invoking a large magnetic pressure in the Local Cavity requires an unreasonably strong magnetic field.
- Response: If the gas is not in pressure balance, then the Local Cloud would be expanding at 10 km s^{-1} which is inconsistent with observations.

- B Stars within the Local Bubble region have outflows that terminate where they interact with the ISM. Therefore, for termination shocks to exist here, there must be material in the LB (Wood 2007).

4.) *Local Cavity and Local Cloud Counter-Argument:*

- A There is an unexplained gap between the LB and the Local Cavity wall, so the Milky Way does contain regions with apparent imbalances in the thermal pressure.
- Magnetic pressure may compensate for the imbalance in thermal pressure.
 - Total pressures need not be balanced if the system is dynamic.

3.1 What measurements are needed to determine how much hot gas may exist in the Local Bubble?

1. More X-ray spectroscopic observations are needed to test the SWCX predictions.
2. X-ray observations with much higher spectral resolution are needed to compare the spectral details of the SWCX models with observed spectra.
3. The high spectral resolution observations must have sufficient spatial resolution for shadowing experiments, in which opaque clouds are used to block the X-rays from more distant diffuse sources.
4. Such high spectral and spatial resolution observations are needed in the 1/4 keV band, which carries much of the flux of the presumably hot ($T \sim 10^6$ K) Local Bubble.

4 Pressure and Energy Balances in the Local Bubble

4.1 Pressure Balance

1. Previously, the LB's thermal pressure had been calculated from the flux of 1/4 keV photons produced between the Sun and a shadowing cloud located ~ 90 pc from the Sun. The resulting thermal pressure was $P_{th}/k \sim 15,000 \text{ K cm}^{-3}$ (Snowden et al. 1998).
 - (a) The LB pressure quoted above is far larger than the thermal pressure of the local warm clouds and other cool gas in the Galactic disk, $P_{th}/k \sim 2200 \text{ K cm}^{-3}$ (Jenkins & Tripp, 2001). The pressure discrepancy between the LB and local warm clouds could be alleviated somewhat if half of the soft X-ray flux previously attributed to the LB is actually due to SWCX ions. Since the flux is proportional to n_e^2 , the thermal pressure is proportional to the square root of the flux. If the LB flux were reduced by a factor of 2, as suggested by Cravens (2000) and Robertson & Cravens (2003), the LB pressure would decrease by a factor of $\sqrt{2}$, but this is not sufficient to explain the large pressure discrepancy between the LB and the local warm cloud pressures.
 - (b) On the other hand, we do not need to invoke SWCX X-rays in order to lower the LB thermal pressure which could be smaller than the estimated $15,000 \text{ K cm}^{-3}$ if the gas is far from CIE. For example, Breitschwerdt (2001) explained the LB's soft X-ray flux as emission from a recombining plasma whose P_{th}/k was only $\sim 2000 \text{ K cm}^{-3}$.
 - (c) Alternatively, a high thermal pressure in the Local Bubble may well be correct; it may be needed to balance the pressure of the material above the LB ($P_{th}/k \sim 20,000 \text{ K cm}^{-3}$, Boulares & Cox 1990).
 - (d) Lastly, it is possible that there is not sufficient pressure support to balance the weight of overlying disk and halo material. Some observations show material moving downwards at $\sim 20 \text{ km s}^{-1}$.
2. If one concludes that the LB does not exist, then one must find some other material to fill the space within the Local Cavity and provide pressure to balance the warm clouds and the overlying material. Suggestions for solving this problem include:
 - (a) Diffuse material having a high magnetic field could provide sufficient magnetic pressure to support the overlying material. Andersson & Potter (2006) found that the magnetic field strength in the plane of the sky is $8_{-3}^{+5} \mu\text{G}$, creating a magnetic pressure of $P_B/k \sim 18,000 \text{ K cm}^{-3}$ on sightlines terminating within about 200 pc of the Sun. However, in his conference presentation, Steve Spangler reported a LB sight

line (toward pulsar J0437-4715, located 170 pc from the Sun), for which the interstellar magnetic field strength is $0.7 \mu\text{G}$. The magnetic pressure along that sight line would be far too small to balance the pressure of the adjacent gas.

- (b) Photoionized gas with a temperature of $T \sim 20,000 \text{ K}$ could fill the space, but such gas may be disallowed by observations.
 - (c) We also considered turbulent pressure and ram pressure. We abandoned turbulent pressure because it does not provide enough support (Redfield & Linsky 2004), but ram pressure could provide significant support (de Avillez 2007).
3. Is the Local Bubble expanding? Probably not. If anything, the Loop I Bubble is expanding into the Local Bubble.

4.2 Energy Balance

- 1. The hot gas in the LB is cooling, but its energy loss is not balanced by energy gain.
- 2. The embedded warm clouds are also losing energy by radiation, but they may also gain energy via photoionization by the extreme ultraviolet and soft X-ray photons from the LB (see Slavin & Frisch, 2002).
- 3. We considered the possibility that heat may be conducted into the clouds from the surrounding hot LB plasma (see Slavin 1989).
 - (a) However, cloud interfaces may be complicated and the conditions on either side of the interface are not well known.
 - (b) If the cloud is surrounded by a tangled magnetic field, then the magnetic field will quench thermal conduction.
 - (c) Some lines of sight through embedded clouds do not contain observable numbers of O VI ions (a tracer of evaporative interfaces), but this may be result from the suppression of thermal conduction by magnetic fields and, therefore, cannot be taken as evidence against the the existence of hot gas in the Local Bubble.

5 Small Scale Structure in the LB

- 1. Warm ($T \sim 8000 \text{ K}$), parsec-scale clouds exist within the LB (Redfield & Linsky 2008).
- 2. One explanation for the presence of such clouds within the hostile environment of the Local Bubble is the Cox & Helenius (2003) model, in which the magnetic field drags material from the LB wall into the interior of the bubble.
- 3. In addition to the population of parsec-scale clouds, there may also be a population of smaller clouds. Scintillation observed in QSO signals implies that very small structures exist in very local ISM (Linsky et al. 2008).
- 4. The very small scale clouds (diameter = 800 to 4000 AU) that exist in the general interstellar medium may also exist within the Local Bubble (see Snezana Stanimirovic's paper in this volume). They could be neutral or ionized and may be fragments from the LB wall, as in the Cox & Helenius model or they may result from collisions of the parsec-scale clouds (Redfield 2007)
- 5. However, evaporation should destroy clouds on Myr timescales unless the clouds are well protected by the magnetic field.

6 Other Important Physical Processes?

1. The standard assumption used when analyzing the X-ray data has been that the gas is in CIE but this assumption should be re-examined.
2. Breitschwerdt & Schmutzler (1994) and Breitschwerdt (2001) computed drastically underionized models of the LB which explained the observed quantity of soft X-ray photons.
3. The Breitschwerdt & Schmutzler scenario is disallowed because the ratios of the observed X-rays to O VI and C III ions and intensity are higher than expected from the model (Welsh et al. 2002; Shelton 2003; Oegerle et al. 2005).
4. In order for the Breitschwerdt & Schmutzler scenario to be valid, the LB's soft X-ray intensity would need to be reduced by a large factor.

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